# Ammonia Emission Inventory Development: Needs, Limitations, and What is Available Now

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## ABSTRACT

Many regions in the country need to develop ammonia emission inventories to clearly evaluate $PM_{2.5}$ levels and visibility degradation. For most agencies, we are beginning this process with little or no previous experience collecting ammonia emission data. This paper discusses what type of ammonia inventory may be appropriate based on the nature of the $PM_{2.5}$ problem within an area. Also described are some of the issues, challenges, and solutions for developing ammonia inventories, as well as a brief case study for cattle ammonia estimates and a summary of some ongoing ammonia related research.

## INTRODUCTION

Ammonia gas can react in the atmosphere to produce particulate matter, such as ammonium nitrate or ammonium sulfate. Because inhaled particulate matter is known to produce negative health effects, it is important to estimate the emissions of particulate matter (PM) and its precursors in those regions with elevated PM levels. Most regions with air quality concerns have already estimated emissions for other PM precursor gases such as oxides of nitrogen, oxides of sulfur, and volatile organic compounds, but they do not have estimates of ammonia emissions.

In preparing an ammonia inventory, it is helpful to evaluate what type of inventory is appropriate to deal with an area's $PM_{2.5}$ problem. For example, regions that are in attainment for particulate matter may meet their needs by developing a general, top-down, inventory using generic emissions and activity data. For other regions, a comprehensive, bottom-up, highly specific, spatially and temporally resolved ammonia inventory may be appropriate for meeting an area's needs to reduce airborne particulates. In this paper, we provide some ideas for evaluating which type of inventory an area may need for developing initial regional ammonia estimates. We will also discuss some of the difficulties we are encountering, and the approaches we are using for prioritizing our efforts and developing ammonia inventory data.

The following topics are discussed in the remainder of this paper.

- Evaluating ammonia inventory needs
- Ammonia inventory preparation planning
- Developing emission estimates
- Current ammonia research

The information provided here is intended to help with the development of initial inventories for regional ammonia emissions. These inventories will allow identification of where additional resources and further refinement will be most beneficial. The initial data can also be used as preliminary inputs to atmospheric models to better evaluate the influence of ammonia on particulate levels in regions with air quality concerns.

## I. EVALUATING AMMONIA INVENTORY NEEDS

In many regions, ammonia emission inventories will be needed to understand the sources of, and the means to reduce, particulate matter levels. This section provides some concepts for evaluating what level of ammonia emission inventory detail may be most reasonable based on the nature of an area's $PM_{2.5}$ problem. The approach is focused on PM inventory development, but it could also be used with some modification for visibility inventory development.

Ammonia is primarily an air quality concern due to its contribution to the formation of particulate matter (PM). Therefore, the PM attainment status of a region will help guide the level of refinement that is suitable for a regional ammonia inventory. For example, if PM levels are low, and there are not problems with PM exceedances or downwind effects, then initially, a general annual average inventory will probably meet regional needs. In addition, if $PM_{10}$ or $PM_{2.5}$ levels are not known, then again it may be reasonable to rely on generalized composite ammonia data, such as the national EPA ammonia inventory estimates[1], until further ambient air quality data are available.

**Evaluation of Direct and Secondary PM**

In regions where direct or secondary PM particulate levels tend to approach or exceed the particulate air quality standards, more refined ammonia inventory estimates may be needed. The estimates will help to identify the major ammonia sources, evaluate their influences, and identify how to reduce particulate levels. In these cases, it is useful to evaluate the types of particulates observed in the ambient air during times of high PM. For example, are the particulates dominated by primary emission sources such as geologic dust or wood smoke? In this case, a highly detailed ammonia inventory would probably not give information that would help in meeting air quality goals. Or, are high PM levels dominated by secondary particulates such as nitrates or sulfates? In this case a detailed ammonia inventory could be instrumental in understanding the causes of high PM levels in the region.

In those areas with high levels of secondary PM, knowledge about the relative ambient levels of precursor gases such as $NO_x$ or $SO_x$, to ammonia levels can also be helpful in evaluating inventory needs. The details are beyond the level of this paper, but as an example, in the situation when $NO_x$ is the limiting substance in nitrate formation, reducing ammonia levels might have little or no effect (in a simplified homogeneous atmosphere) in reducing PM levels. Therefore, it may not be warranted, at least initially, to develop a fully gridded, temporally resolved modeling inventory for ammonia because it may not be needed to meet air quality objectives. In contrast, when it appears a region may be ammonia limited, a more detailed ammonia inventory will probably be needed to effectively evaluate control strategy development.

By developing a conceptual model of potential emission sources and the contributors to PM or visibility problems, it is possible to formulate ammonia inventory requirements based on the regional air quality improvement needs. It is then possible to tailor the inventory elements, listed below, so that they best meet air quality planning and modeling needs.

- Number of sources inventoried
- Completeness of the activity data collected
- Specificity of the emissions rate data used
- Level of spatial and temporal refinement

## II. AMMONIA INVENTORY PREPARATION PLANNING

In preparing an ammonia inventory, it is worthwhile to prioritize which of the many potential ammonia sources should receive attention. Table 1 provides a list of ammonia sources that can be used to evaluate which sources are present within a region. These sources may then be ranked in terms of priority for estimating emissions. To assist with this, the table provides a simple, semi-quantitative method for prioritizing and documenting the initial source significance.

The ranking approach includes several subjective factors including the relative importance of the source based on policy, health, and other concerns; the expected magnitude of emissions from the source; the quality of the existing emission factors and activity data; and the availability of spatial and temporal allocation data for the source. The ranking takes into account what is known, but also what is unknown, and is designed to give the highest scores to the sources with the greatest uncertainty and the highest potential emissions.

For illustration, the table is populated with values used to evaluate California statewide ammonia inventory priorities. Values are summed across the rows to get scores. However, to reduce some of the influence of the spatial and temporal data, which are of secondary importance for the first draft inventory, they were divided by two prior to summing. Note that the sources with high scores are a combination of those that are likely to have high emissions, such as livestock, and those with high uncertainties, such as ammonia from soils or biomass burning.

In completing the prioritization table, it may be unclear what to input to the source magnitude column. To assist with this, Table 2 provides a comparison of the emissions levels from typical ammonia producing activities. These are rough estimates based on generic emission factors and activity data. The example activity data were selected to show the emissions for representative facility sizes and emission sources, and are meant to provide order-of-magnitude comparisons only. If the type and number of ammonia sources are known within a region, these data may be of help in giving some indication of emissions levels.

In addition, Figure 1 also shows some pie charts from previous inventories, which may be helpful in evaluating the relative emission magnitudes of various ammonia sources. Note the tremendous variations in source contributions for these inventories. The national inventory shows that 80% of the ammonia emissions are from livestock. The San Joaquin Valley inventory shows that 42% of ammonia is from soil, but the national inventory purposely excludes soil emissions because of their high level of uncertainty and the capability of soils to emit and uptake ammonia. Unlike the San Joaquin Valley and national inventories, the Southern California estimates include significant emissions from domestic and point sources.

An important point here is that there is tremendous range of possibilities in preparing and presenting ammonia emission estimates. Some of the variations shown in the pie charts are due to differences in ammonia emissions, but many of the variations are due to differences in methodologies and which sources were inventoried.

For this planning process, the objective is to create a general strategy to begin development of an initial inventory. Then, as inventory development proceeds and more information is gathered, the inventory and priorities can be modified as needed to meet air quality goals. Therefore, detailed ammonia literature reviews, needs assessments, or planning studies are probably not necessary.

**Table 1.** Ammonia Sources and Priority Scoring for Inventory Development Needs.

| | | a | b | c | d | e | f | g |
|---|---|---|---|---|---|---|---|---|
| | | Primary Score Categories | | | | Secondary Scores | | |
| **Source Type** | **Source Name** | **Source Importance** | **Source Magnitude** | **$NH_3$ EF Quality** | **Activity Data** | **Spatial Data** | **Monthly Temporal** | **Totals** |
| Livestock | Beef | 5 | 4 | 3 | 2 | 2 | 4 | 17.0 |
| | Dairy | 5 | 4 | 3 | 2 | 2 | 4 | 17.0 |
| | Poultry | 4 | 3 | 3 | 3 | 3 | 4 | 16.5 |
| | Swine | 3 | 2 | 3 | 3 | 3 | 4 | 14.5 |
| | Horses | 2 | 2 | 3 | 3 | 4 | 4 | 14.0 |
| Fertilizer | Agricultural | 4 | 3 | 4 | 2 | 2 | 4 | 16.0 |
| | Commercial | 3 | 2 | 4 | 3 | 3 | 4 | 15.5 |
| | Residential | 3 | 2 | 4 | 4 | 2 | 4 | 16.0 |
| Soil | Disturbed soil | 4 | 4 | 4 | 4 | 3 | 5 | 20.0 |
| | Natural soil | 4 | 4 | 4 | 4 | 3 | 5 | 20.0 |
| Stationary | Waste water treatment | 3 | 2 | 3 | 2 | 1 | 4 | 12.5 |
| | Ammonia injection | 3 | 1 | 3 | 2 | 2 | 3 | 11.5 |
| | Geothermal | 1 | 3 | 2 | 2 | 1 | 2 | 9.5 |
| Motor Vehicles | MV Catalysts | 3 | 3 | 3 | 3 | 3 | 2 | 14.5 |
| Other Industrial | Refrigeration | 2 | 2 | 3 | 3 | 4 | 2 | 13.0 |
| | Fertilizer production | 2 | 1 | 3 | 2 | 2 | 2 | 10.0 |
| | Ammonia production | 2 | 1 | 3 | 2 | 2 | 2 | 10.0 |
| | Others | 1 | 1 | 3 | 3 | 3 | 3 | 11.0 |
| Other Area Sources | Compost & Landfills | 2 | 2 | 4 | 5 | 3 | 4 | 16.5 |
| | Biomass burning | 2 | 2 | 4 | 5 | 3 | 4 | 16.5 |
| | Human & domestic | 2 | 1 | 5 | 4 | 4 | 3 | 17.5 |
| | Pets | 2 | 1 | 5 | 4 | 4 | 3 | 15.5 |
| | Wildlife | 1 | 1 | 5 | 5 | 5 | 5 | 15.5 |
| | **Scoring Criteria** | 5 = most important | 5 = most important | 1 = highest quality | 1 = highest quality | 1 = highest quality | 1 = highest quality | |
| | | | | | | x ½ | | |

**Description of Scoring Categories**

| | |
|---|---|
| a - Source Importance | Based on magnitude, perception, public awareness, existing resources, industry interest, potential for control, potential toxicity |
| b - Source Magnitude | Estimated based on previous ammonia inventories, number of sources, Chemical Mass Balance (CMB) data |
| c - EF Quality | Score based on estimated uncertainty and variability of existing emission factors (EFs) and complexity of source category |
| d - Activity Data Quality | Estimation of quality and availability of overall annual activity data; includes detail available and expected newness of available data |
| e - Spatial Data* | Availability of spatial data; general quality and resolution expected to be available |
| f - Monthly Temporal* | Availability of data which could be used to estimate monthly variations in emissions |
| g - Totals | This is the total prioritization score. Score = (a+b+c+d) + (e+f)/2 |
| * Note on e & f | *The spatial and temporal column scores are multiplied by ½ prior to summing because they are of less significance in preparing an initial inventory |

**Table 2.** Comparison of Example Ammonia Emission Sources.

| Source | $NH_3$ Emission Factor | Activity Data Examples | Emissions (tons/yr) | Comments |
|---|---|---|---|---|
| Dairy | 70 lbs/head/yr | 585 head | 20 | EF from population weighted dairy cattle avg. Battye[2] Table 2-9. Average herd size of 585 from CDFA[3], 1997. |
| Feedlot | 47 lbs/head/yr | 2000 head operation<br>15,000 head | 47<br>352 | EF from population weighted beef cattle average/Battye Table 2-9. Most CA cattle in 1000+ size operations. |
| Grazing | 18.1 lbs/head/yr | 2000 head | 18 | EF from Asman (via Battye, Table 2-1). Herd size arbitrary. |
| Poultry | 0.393 lbs/head/yr | 200,000 head | 39 | EF from population weighted composite from Battye Table 2-9. Flock size arbitrary. |
| Water Treatment | 16 lbs/$10^6$ gallons | 20 million gallons/day<br>75 mgpd facility | 58<br>219 | EF from Battye Table 6-2 based on CA POTW data. 20 mgpd moderate size treatment works. 75 mgpd large urban. |
| Fertilizer | 167 lbs/ton urea<br>19.7 lbs/ton $NH_3$ | 10 square miles<br>(=6400 acres) | 15 | EF Battye, Table 3-5, Wt. % Table 3-1. Arbitrary assumption to apply 50 lbs urea & 50 lbs anhydrous ammonia/acre to get average mix (not realistic operational scenario). 100 lbs fertilizer/acre is realistic application rate. |
| Soil | 1 lb/acre/yr | 10 square miles | 3 | EF from Schlesinger via Battye Table 6-3. Temperate grassland, range is 0.1 to 10. Arbitrarily selected 1 for analysis. |
| Autos | 216 lbs/$10^6$ VMT | 100 million VMT | 11 | EF Fraser and Cass[4]. EF for fleet average adjusted for catalyst mix & high $NH_3$ emitters. |

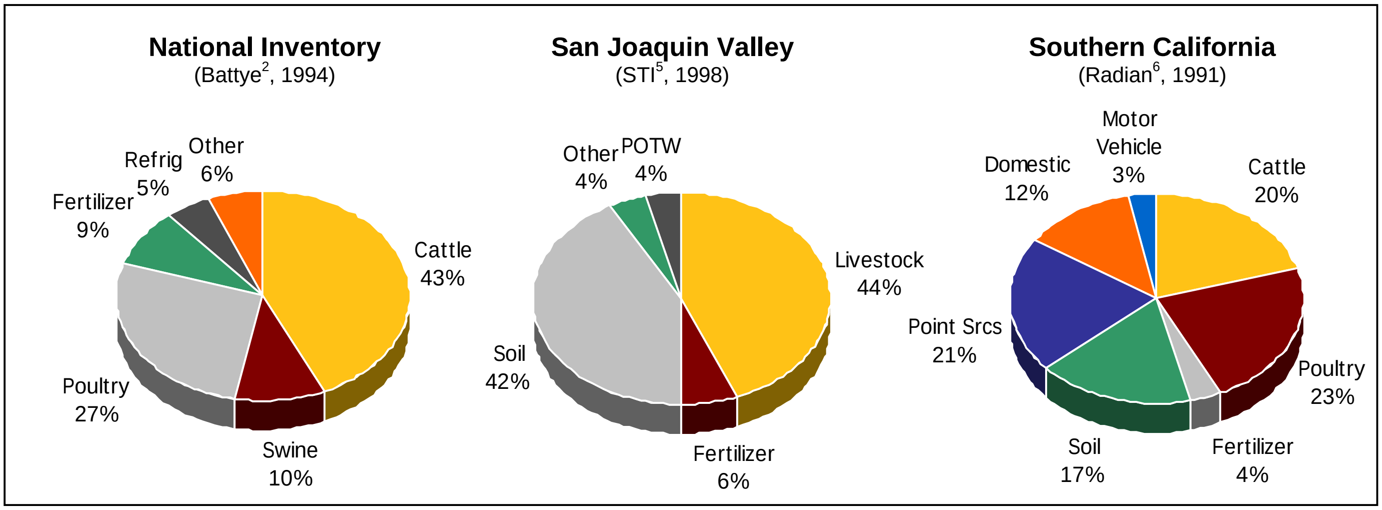


**Figure 1.** Ammonia Emission Inventory Examples.

## III. DEVELOPING AMMONIA EMISSION ESTIMATES

Most of the potentially significant sources of ammonia are dispersed, area-wide sources such as livestock, fertilizer application, and motor vehicles. Because it is difficult to gather consistent and locally applicable emissions and activity data for these types of sources, emission estimates will have substantial uncertainty. To add further uncertainty, the inventory data must be input into atmospheric models, much like for ozone, to evaluate how much of the ammonia reacts to produce secondary particulates. Therefore, even with a perfect inventory, the results will still be subjected to the significant uncertainties of atmospheric modeling to evaluate the contribution of ammonia to PM levels or visibility degradation.

With these inherent uncertainties, it is sensible to identify and estimate emissions from the large, major sources first, evaluate their influence on PM or visibility, then refine emission estimates for the smaller contributors as needed. The remainder of this section discusses some of the problems we have encountered in preparing ammonia estimates and how we are dealing with them.

**Emission Factors**

Numerous studies have been funded to compile and tabulate emission factor data for the various ammonia sources[2,5,6]. These compilations are helpful in providing a range of possible emission values for developing an inventory, but substantial judgement is necessary in selecting the specific values needed for emission estimates.

To develop a detailed, region specific inventory, it is important to know if the ammonia emission rates were developed using mass balance approaches, emissions testing, some type of engineering analysis, or another technique. It is also helpful to evaluate what assumptions went into the emission factors. For example, if testing was performed for dairy cattle, does it include just the direct animal waste emissions? Does it also include emissions from manure piles, storage ponds, and other site emission sources? Are the animals grazing for feed? What is the nitrogen content of their diet? How are they housed? How many are present at a single facility? What is the waste removal technique? Understandably, most summary reports do not provide the level of detail need to answer these questions, and most of us do not have the resources to evaluate the primary literature.

A cursory look at any of the published emission factors for ammonia sources shows a wide range of emission possibilities. For example, emissions from soils[2] range from 0.1 to 10 lbs of ammonia per acre. Dairy cattle emission factors range from 20 to 130 lbs per animal per year[7,6]. Because of this large variability and lack of region specific data, it is useful to select the most sensible emission factor data available, and then develop methods that can be easily updated with new or more appropriate data as they become available.

With this perspective, the emission factors already provided in the existing published literature are probably adequate for initial ammonia inventory development. A helpful reference for emission factors is the report, "Development and Selection of Ammonia Emission Factors" [2] which was funded by the U.S. EPA. This document is available on the EPA web site at: http://www.epa.gov/ttn/chief/efdocs/ammonia.pdf. This report provides more detail than many of the other published documents and provides descriptions of the sources and issues involved. A partial summary of emission factors for the major source categories is also posted on the ARB website as part of a previous ammonia inventory presentation[8]. The address is http://arb.ca.gov/emisinv/pmnh3/pmnh3.htm.

**Activity Data**

The emission factors for ammonia sources dictate what type of activity data are needed or appropriate. For example, beef cattle have emission factors for adults, calves, and other subcategories, so it makes sense to seek population data for these animal types. Similarly, fertilizer emission factors are provided for anhydrous ammonia, urea, and others, so again, the emission factors help to establish what fertilizer sales and application data are needed to prepare an inventory.

As with the emission rates, there is substantial uncertainty for the ammonia activity data, and in some cases, it is difficult to even obtain these data. For example, how many chickens are there in Arkansas? How much fertilizer is applied in North Dakota? What kind? When? How many cars are emitting ammonia in California? The principle is the same here as with the emission factors – it is worthwhile to make an initial estimate with whatever is available and refine as needed.

**Review of Estimates**

When an inventory method and estimates have been completed, an essential step follows. It is very beneficial to have the emission factor, activity data, and methodology reviewed by experts from the affected industries, academic researchers, and other air quality scientists. It is useful to explain what assumptions were made and why, what the method's shortcomings are, and how the data will be used (e.g., trying to determine which sources might possibly be significant). Working with industry and others also provides an opportunity to determine if there are better available sources of activity data, seasonal data, and spatial data.

**Summary of Issues for Major Source Categories**

The following list provides a summary of issues and difficulties in estimating emission for the most obvious ammonia sources. The information is summarized from reports listed in the references, and it is provided to help identify some of the problems to keep in mind while collecting the data needed to prepare a source inventory.

- *Livestock*
  - difficult activity data collection due to various animal types and residency time issues
  - emission factors have wide variations and are not standardized; specific sources, handling practices, and housing practices difficult to estimate
  - emission factors do not take into account differences in temperature, humidity, soil, and other factors that can affect ammonia formation and volatilization
- *Fertilizers*
  - wide range of emission factors; effects of climate and soil difficult to incorporate
  - most emission factor data are based on theoretical calculations and laboratory study
  - need application methods, application calendars, and spatial allocation data
- *Soils*
  - soils emit and uptake ammonia so it is difficult to evaluate the net contribution; emissions potentially significant in some regions if uptake is not substantial
  - may need to model the emissions related to vegetation coverage, climate, and soil type as is done with biogenics
  - limited emission factor and test data are available, wide range of values
- *Industrial sources*
  - generally minor emissions, ammonia used as part of process or product, so efforts are made to limit losses for economic reasons

- *Sewage treatment*
  - there is concern about ammonia losses prior to effluent reaching the treatment plant
  - individual facility emissions can sometimes be significant, but often overwhelmed by other regional sources
  - limited emission factor data available, but activity data easy to obtain for facilities
- *Domestic/urban sources*
  - domestic sources such as cleaning products, pets, diapers may need to be evaluated
  - sources appear to be minor emission contributors, but may need to inventory for equity and to understand higher than expected ammonia levels in some urban regions
- *Motor vehicles*
  - emissions could be significant for urban areas
  - substantial variability in vehicle ammonia emissions within fleet
  - first order estimates may be possible with existing motor vehicle inventory data and literature emission factors

## IV. CASE STUDY: PREPARING A BEEF AND DAIRY CATTLE INVENTORY

The following discussion about preparing a cattle emission inventory illustrates some of the issues involved in estimating emissions from many of the non-point ammonia sources. As with many sources, the basic approach for estimating ammonia from cattle is simple enough: develop an emission factor by measuring ammonia emissions from a typical population of animals; count the number of animals that are present over the course of a year; then, multiply the emission factor by the number of animals to get the annual cattle ammonia emissions.

Unfortunately, the situation is far from being this simple. In estimating emissions from beef and dairy cattle there are a myriad of issues to consider. What kinds of animals are present? What is a typical population? How long are they present? Is there information available to estimate emissions for the various animal types? Is there data to evaluate how animal populations vary over the course of a year? How do practices change by season? Is manure stockpiled and disposed at distinct times of year? And, how do emissions change as a result of variations in climate, soil, and other factors?

For areas with PM exceedances driven by secondary particulates, all of these questions are relevant for understanding and modeling the seasonal and local variability of the emissions. This is important because in most regions, the effects of cattle ammonia emissions are not an annual problem, but a season specific, somewhat localized concern. Fortunately, although the estimates will be far from perfect, with existing data it will be possible to determine where the sources are, estimate their emissions, and evaluate what time of year they are likely to be most significant.

### Activity Data – Population

As stated previously, one of the ways to evaluate what activity data are needed for an emission source is to look at what emission factors are available. For cattle there are factors for beef cattle, dairy cattle, young cattle, grazing cattle, calves, cows that have calved, heifers, animals 500 pounds and over, and of course, bulls[2]. From all of these choices, it is necessary to determine which population data are actually available on a regional basis. In California, beef and dairy cattle population data are available from the California Department of Food and Agriculture[3], and the California Agricultural Statistics Service[9]. For beef and dairy cattle, data were available to estimate populations for the population classes shown in Table 3. These classes were selected because there is information available to estimate the populations, as well as a relatively consistent set of emission factor data that can be used with the population data to perform emission estimates.

For livestock, it is important that the population estimates not be based strictly on sales or unexamined population figures, which can cause substantial miscounting. For example, feedlot animals typically are only kept about six months, so a feedlot might sell 100,000 head in a year, but that doesn't mean that 100,000 head of cattle were producing emissions over 12 full months. Instead, assuming a six-month residence time, 50,000 animals may be present from January through June, then they are sent to market, and another 50,000 arrive from July through December. Therefore, over the course of the year, there are emissions from only 50,000 animals that are actual residents for 12 months, not 100,000, which is the number marketed. There is a similar situation with inshipment cattle that are brought into California for only about seven months for grazing, so a straight count of the animals would not provide a correct estimate of the number of animals emitting per year.

Once it is determined what types of animals are present, it can be determined where they are located and when they are present. For the initial ARB methodology, information was available from the state agricultural agencies to apportion the cattle by county. As the method is refined by working with industry groups, efforts will be made to better spatially and temporally apportion emissions for those regions significantly affected by ammonia emissions.

**Emission Factors**

The emission factors for cattle have a wide range of values ranging from 11 lbs $NH_3$/head/year for range calves[2] to over 130 lbs of $NH_3$ head/year for dairy cattle[6]. As mentioned previously, selecting data from the existing literature is difficult because the researchers use different methods, applied to different types of operations, under different conditions. To add further difficulty, much of the ammonia research has been performed in Europe which raises questions about the applicability of these data to practices used in the United States.

In preparing first draft estimates we selected a set of emission factors that provided a level of consistency among the animal types, and appeared to take into account some of the differences in animal handling practices such as range feeding, stable housing, manure spreading, and waste storage emissions. Our current emission factor selections, shown in Table 3, are on the low range of published factors and are provided in Battye[2]. Because of the variability in the emission factors, one approach we are considering is including a range of emissions estimates, possibly based on average emissions rates.

**Table 3.** Beef and Dairy Cattle Classes & Emission Factors.

| **Beef Cattle** | **Emission Factor** (lbs/head/yr) | **Dairy Cattle** | **Emission Factor** (lbs/head/yr) |
|---|---|---|---|
| Range adults | 18.12 | Dairy cow | 37.58 |
| Inshipments | 18.12 | Milk calves | 11.53 |
| Calves | 11.52 | Milk heifers | 28.75 |
| Feedlot animals | 33.49 | Dairy bulls | 61.53 |

With the emission estimates completed and a well-documented methodology, our next step is to provide the information to the agricultural industry and others interested in ammonia estimates for review. We will then hold a meeting with the reviewers to discuss the methods, shortcomings, and ways to improve the estimates. For more detailed information on our approach, the complete draft methodology for this beef and dairy cattle ammonia estimates will soon be posted at http://arb.ca.gov/emisinv/pmnh3/pmnh3.htm.

## V. ONGOING AND PLANNED RESEARCH

It is important to be aware that there are numerous studies that have evaluated what ammonia emission data and methods are available, and what future research is needed[2,5,6,10,11,12]. Therefore, it is necessary to carefully target research efforts when funding further efforts in this area. At this time it is important to perform source specific research that will tangibly improve our emission inventories and provide a better understanding of ammonia emissions and variability. The following research studies are sponsored by the ARB and others to meet some of these goals.

To help better understand emissions from fertilizer application, the ARB is sponsoring a project with California State University, Fresno, and the NASA Ames research center. The project will measure ammonia emission rates from fertilizer application and then develop regional fertilizer emissions modeling based on the field test data. The project will test emissions for a variety of fertilizer types and application methods relevant to the major crop types in California's San Joaquin Valley. The modeling will include inputs for soil type, climatic conditions, application calendars, and other relevant factors. The project will also attempt to evaluate background agricultural soil ammonia levels by beginning ammonia sampling prior to the fertilizer application.

The ARB also has a project with the National Oceanographic and Atmospheric Administration to develop and evaluate a Lidar laser system to measure real-time, three-dimensional ammonia concentrations. For the longer term, the ARB is also evaluating the need to develop a GIS based model, which could estimate and display ammonia emissions in a way similar to biogenic emissions.

The California Regional Particulate Air Quality Study (CRPAQS) is planning to fund studies which will improve our emission estimates from commercial and residential fertilizer application, as well as collecting data which can be used to more clearly estimate ammonia emissions from urban sources such as household products, pet waste, diapers, and other unsavory sources. This work will help us better understand some of the sources that do not always receive much attention, but may possibly play a consequential role in nitrate or sulfate formation because their proximity to $NO_x$ sources.

Within the ARB, our Mobile Source Control Division is performing some limited testing of ammonia from motor vehicles to begin a more complete evaluation of these emissions. These emissions, which are not included in our emission estimates, may be important contributors to PM formation. In a simplified estimate performed by Mathew and Cass[4], they showed that motor vehicle ammonia emissions may be as high as the dairy emissions in Southern California, which are in the range of 25 tons per day. These results are not comprehensive, but they do indicate that additional work is needed in this area.

The South Coast Air Quality Management District has also recently received the results of a contract they sponsored to develop a comprehensive, gridded ammonia emission inventory for Southern California. This report is one of the most recent, and probably among the most comprehensive regional ammonia inventories developed. These proceedings also include papers discussing swine ammonia emissions. Some of the work, protocols, and methods in these papers will be helpful for estimating ammonia from other ammonia sources, especially livestock.

There is additional ammonia work being sponsored by several agencies. At this time, it appears that what is needed most is specific emission rate information, better estimates of environmental variability, and resources to compile appropriate levels of activity data.

## VI. CONCLUSIONS

In some regions of the United States, it is important to develop detailed, well-defined ammonia emission inventories appropriate for modeling. Other areas will be able to meet their needs for understanding the contributions of ammonia to air quality and visibility degradation with more general emission estimates. Because of all of the work we constantly have before us in improving air quality, it is important to clarify and prioritize which sources need the most attention, and what work will provide the greatest benefit.

Preparing ammonia inventories is a challenge because of the tremendous range in emission factors, the difficulty in collecting activity data, the climatic and other variations in the emission rates, and the often diffuse and poorly understood emission sources such as livestock and soils. These data must then be input to atmospheric models, with their own uncertainties and approximations, to fully understand the effect of the ammonia on air quality.

Fortunately, there is adequate information available to prepare initial inventories that can then be extended to the level of detail warranted by regional air quality and visibility improvement needs. There is also adequate time to prepare ammonia inventories that will meet regulatory requirements. In California, we plan to have a draft statewide ammonia emission inventory available in 2001. The inventory will include all of the major ammonia sources and will include some spatial and temporal allocation of the emissions. Additional inventory efforts will be focused on those areas with known secondary PM problems to better refine the information needed for modeling. With these data, we can begin to more clearly understand the effects of ammonia on air quality, and provide information that will be helpful in continuing to improve the air quality within California.

**DISCLAIMER**

The opinions, findings, and conclusions expressed in this paper are those of the staff and not necessarily those of the California Air Resources Board. In addition, the opinions provided regarding the needs and priorities for developing ammonia inventories are strictly those of the authors and have no regulatory authority.

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Key Words

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